Application of Infrared Thermography in Power Distribution System

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ABSTRACT

Electricity sector of Pakistan is facing daunting energy crisis. Generation deficit results in long duration of load shedding throughout the country. Old aged distribution system, lack of maintenance and equipment failure cause long unplanned outages and frequent supply interruptions. HESCO (Hyderabad Electric Supply Company) is facing high technical losses, supply interruption and financial loss due to transformer damages. IR (Infrared) Thermography is non-contact, safe and fast measure for distribution system inspection. In this paper, thermographic inspection for different distribution system equipment is carried out to identify possible developed faults. It is observed that IR thermography is effective measure for detecting developing faulty conditions at the initial stages to avoid unplanned outages.

Key Words: **Distribution System Maintenance, Hyderabad Electric Supply Company, Infrared Thermography, Transformer Damage.**

1. INTRODUCTION

Nowadays Pakistan is facing its historical exacerbated energy crises due to multi-folded reasons noticeably due to vulnerable aged equipment, system overloading, mismanagement of resources, line losses, theft issues and most importantly questionable monitoring and control [1]. The power sector of Pakistan comprises of two main power utilities, i.e. PEPCO (Pakistan Electric Power Company Limited) and KESC (Karachi Electric Supply Company). KESC is privatized and it specifically covers Karachi city, while PEPCO covers the rest of the country. PEPCO is further categorized into nine DISCOs (Distribution Companies).

HESCO is one of the distribution company which is responsible for distribution of electric power to lower Sindh province in Pakistan [2]. Service area of HESCO is 70458 sq.km having consumers in both rural and urban areas. HESCO distribution network has about 3000 km of 132 and 66kV primary distribution network, 69 substations and 415 feeders to distribute power to its service area. Length of overhead HT (High Tension) and LT (Low Tension) lines are 26143 and 14049 km respectively. About 100 thousands residential, commercial, agriculture and industrial consumers are supplied through this vast service area.

HESCO has an old network where preventive maintenance and network expansion were ignored for several years despite rapid growth in load. Generation deficit and distribution system faults result in supply outages exceeding ten hours a day. Frequent tripping of 11kV feeders worsens the scenario. As a result, life of Consumer appliances and utility equipment is being decreased. HESCO distribution system losses are claimed to be near 30% whereas in developed countries these losses are less than 4%. Electricity theft is considered major cause for losses but technical losses

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are also on the higher side. Some of the feeders have more than 10% technical losses [3].

Distribution system in HESCO has huge number of joints and terminations. Transformer bushing connections, conductor joints, cable terminations and other connection points are unavoidable parts of the system. Lack of quality workmanship results in increased resistance at these points. Old conductors and cables develop frequent faults due to overloads. The restoration of supply after the occurrence of fault is not made according to the standard procedures leading to lose joints and increased resistance at these joints. Consequently, power losses increase and faults reoccur at these joints only to cause repeated outages.

Maintenance is considered as adding an additional capacity to system [4]. Lack of proper maintenance affects power system from generation to transmission to distribution lines. Maintenance helps to reduce long outages and increase life of system components. Huge amount of money can be saved by proper maintenance before any equipment suffers considerable damage. One of the common examples is the burning of distribution transformers in HESCO, causing loss of money, long outages and consumers' dissatisfaction.

IR thermography is technique used to detect developing abnormal conditions and predicative maintenance requirement especially in developed countries. In Pakistan, IR thermography is rarely considered for electric power utilities. This technique can be successfully used to predict maintenance requirement, lose contacts and unbalanced loading.

Jadin, et. al. [6] used IR thermography for electrical systems in buildings to detect problems [5]. Lehtiniemi, et. al. investigated use of thermography for different electronic equipment. Che-Wung, et. al. [7] suggested that IR thermography is best method to detect problems in medium voltage cable system in nuclear power system. Almeida, et. al. [8] considered thermographic inspection for monitoring of surge arresters. They concluded that operation and maintenance of surge arresters is observed clearly from thermographic inspection. Galvan et. al. [9] considered hot spot in transformer body caused by stray currents causing overheating of the screws and other mechanical parts of the transformer. They suggested that IR thermography is safe and reliable method to detect such problems.

This paper investigates various fault conditions in distribution system and their detection using IR thermography. Paper contains laboratory experiments related to power losses in electrical joints. Field visits were carried out to observe the problems using thermographs. The results are analyzed and recommendations are given to incorporate IR thermography for better performance of distribution system in HESCO.

The remainder of this paper proceeds as follows. In Section 2, the basics of Infrared Thermography are discussed followed by two laboratory experimental tests to investigate the power loss detection using thermography in Section 3. In Section 4 the use of thermography in distribution system is analysed by considering different fault conditions in distribution system specially focusing on transformers located at diverse locations, followed by a conclusion in Section 5.

2. INFRARED THERMOGRAPHY

Two Latin words infra (below) and red combine to form IR referring frequency below that of red [10]. In other words it refers to invisible light with wavelength higher than red. Electromagnetic radiation with frequency of 1 and 430 THz and wavelength between 0.7 and 300 micrometers is called infrared radiation [11]. Every particle emits heat and this heat is called thermal radiation. Its wavelength is high and therefore, it falls in infrared category. Infrared energy emitted by an object increases with increased temperature. Observing radiated heat with the help of thermal imagers is thermography. Thermal image is found by converting radiated heat into visible image. Differences in temperatures are then analyzed to conclude a result. Being a non-contact method it is a safe and reliable method for measuring temperature of very hot bodies and even when target is moving [12]. IR thermographic cameras are available to convert radiated heat into a thermal image. This image can be used for temperature based analysis.

The ratio of energy radiated by any specific material to energy radiated by a black body at the same temperature is called emissivity of the material [13]. A black body is considered as reference and having emissivity equal to 1. All other materials will have emissivity value less than1. Therefore, it can be considered as relative capability of its surface to emit energy by radiation. Lower the reflection ability of material, higher will be its emissivity [14]. Knowledge of emissivity for different material will help to analyze a thermal image and estimate temperature with more accuracy. Emissivity values are some of the commonly used materials are given in Table 1.

Thermography is helpful to monitor various electrical and mechanical problems including lose connections, corrosion, unbalanced loading, overloading, shaft misalignment, worn out bushing and bearings, over and under lubrication, gear box, excess frictions and many more.

3. POWER LOSS DETECTION USING THERMOGRAPHY

Current (I) flowing through any component having resistance (R) will dissipate power loss (equal to I^2R) in the form of heat. The heat will increase whenever there is increase in I or R. Increased heat will increase temperature of the component and thus more heat will be radiated. This change in temperature can be visualized at an early stage using infrared thermography. Lose contacts and joints are commonly found in distribution system of HESCO. For a joint or termination, sufficient contact area between two parts is required to allow proper current flow and reduce power loss. Lose contacts and improper joints have higher resistance than normal resulting in higher current flow and power loss in the form of heat. Poor workmanship and haste in restoration of supply after an outage, are major causes for lose joints. Distribution system in HESCO is a system full of joints and unfortunately most of these re-made improperly. Therefore, technical losses are increased.

TABLE 1. EMISSIVITY VALUES FOR DIFFERENT MATERIALS

Material	Emissivity
Aluminum Oxidized	0.30
Copper Oxidized	0.65
Steel Oxidized	0.85
Iron Oxidized	0.74

3.1 Laboratory Experimental Tests and Results

In the following section two different experimental tests have been conducted to verify the effect of lose and tight connection when any load is connected.

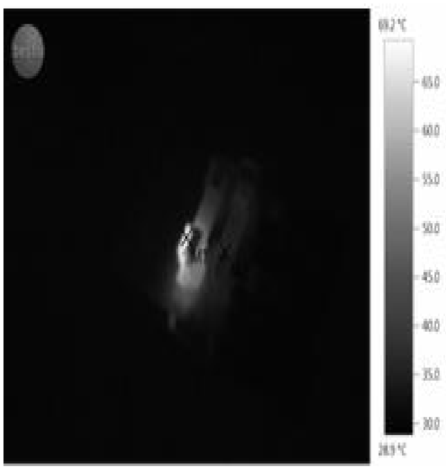
3.1.1 Experiment-1

To detect the power loss due to lose contacts using thermography, a laboratory experiment is conducted with two fuses. One fuse was made with a lose contact and other properly connected. 1kW load was supplied through both fuses. Fig. 1(a-b) show experiment arrangement and its thermal image respectively. Observed results are given in Table 2. It is clear that with lose connection the recorded power loss is of 8W as compared to 6.4W for tight connection. 1.6W increase in power losses is observed when connected load is only 1kW. Voltage drop also increases by 0.4V for lose contact. Increased power loss is identified by an increase in temperature from 35.1^0C (marked X_{M2}) to 39.2^0C (marked X_{M1}) (by the margin of 4.1^0C) by thermographic camera. Relative temperature measurement is difficult without thermographic camera. It is, therefore, concluded that for this case thermography detects power loss caused by lose contacts.

3.1.2 Experiment-2

In second experiment two CB (Circuit Breakers) are used in series to supply a load of 2kW. One circuit breaker is tightly connected whereas other has a lose connection as shown in Fig. 2(a-b). Observed results are given in Table 3. It can be observed that a lose connection with CB 2 increases power loss by 6.4W (16W compared to 9.6W) for connected load of 2kW. Also there is a voltage drop 0.4V for lose contact. Corresponding change in temperature indicated by thermal image is from $34\text{-}39.1^0$C (difference of 5.1^0C). Hence it is clear that temperature rise shown by thermographs represent power loss caused by lose connections.

(a). FUSES ARRANGEMENT FOR LABORATORY EXPERIMENT-1



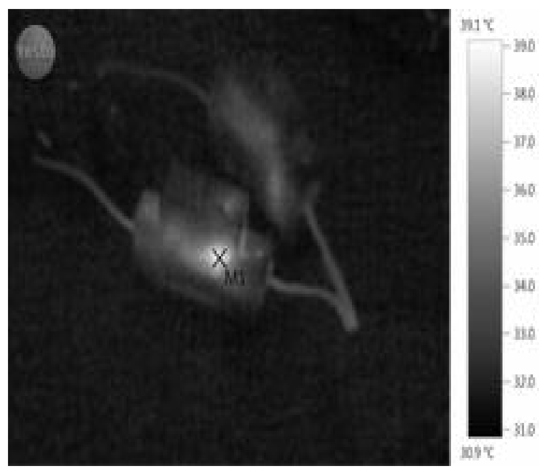
(b). CAPTURED THERMAL IMAGE FOR LABORATORY EXPERIMENT-1

FIG. 1. FUSES ARRANGEMENT AND CAPTURED THERMAL IMAGE FOR LABORATORY EXPERIMENT-1

TABLE 2. COMPARISON OF TIGHTENEN AND LOSE FUSE CONNECTIONS FROM LABORATORY EXPERIMENT-1

Parameter	Fuse-1 (Tightened)	Fuse-2 (Lose)
Supply Voltage (V)	220	220
Supply Current (A)	4	4
Voltage Drop (V)	1.6	2
Dissipated Power (W)	6.4	8
Measured Temperature (^{0}C)	35.1	39.2

(a). CIRCUIT BREAKERS ARRANGEMENT FOR LABORATORY EXPERIMENT-2



(b). CAPTURED THERMAL IMAGE FOR LABORATORY EXPERIMENT-2

FIG. 2. CIRCUIT BREAKERS ARRANGEMENT AND CAPTURED THERMAL IMAGE FOR LABORATORY EXPERIMENT-2

TABLE 3. COMPARISON OF TIGHTENEN AND LOSE CIRCUIT BREAKER CONNECTIONS FROM LABORATORY EXPERIMENT-2

Parameter	Circuit Breaker-1 (Tightened)	Circuit Breaker-2 (Lose)
Supply Voltage (V)	220	220
Supply Current (A)	8	8
Voltage Drop (V)	1.2	2
Dissipated Power (W)	9.6	16
Measured Temperature (^{0}C)	34	39.1

Experimental results confirm that lose connection increases power loss and such connections are detected safely and accurately by thermography.

4. THERMOGRAPHY IN DISTRIBUTION SYSTEM

Thermographic inspection of distribution system including transformer bushings, line conductors/cables, service connections, circuit breakers, fuses and distribution panels can be performed using thermal imagers. Current flowing through resistance causes power loss and temperature rise. The fact implies that change in operating conditions will cause a change in relative temperature as proved by two given laboratory experiments.

Distribution transformers from 10-1500kVA are used in distribution system of HESCO. Transformer damage is common problem in HESCO resulting in loss of money and long outages for consumers. Overloading, load unbalancing and improper protection are major causes of transformer damage. IR thermography is simple, reliable and safe method to detect overloading and unbalanced loading. Thermographs can be taken from ground at different time intervals to check for any problem. Fig. 3 shows thermograph of a distribution transformer located at Qasimabad city, Hyderabad having unbalanced loading. One bushing is at a higher temperature indicating more load on that phase. It is then confirmed from the current measured at outgoing leads from LV bushings. Currents measured for three phases of 200kVA transformer are 273, 208 and 394 Amperes. Thermograph shows temperatures of 59.4, 42.4 and 91^{0}C respectively for three phases. It is quite obvious from the results that unbalanced loading can be detected easily by thermographs.

Transformers are observed to have lose connections at bushings causing increased power loss. Lose connections convert in open circuits resulting in power outages and unbalanced operation of the transformer. Fig. 4 shows 200kVA transformer installed at MUET (Mehran University of Engineering & Technology), Jamshoro, Pakistan having lose connection at one high voltage bushing. Temperature of hot spot is 185^{0}C compared to other bushing where temperature is 84^{0}C. This lose connection identified by hot spot in thermograph can be repaired to avoid any disturbance and discontinuity in supply.

Drop out fuses are used on high voltage side of the transformer to provide protection for the faults in transformer and its secondary network. Proper sized fuses are required but rarely used. Mostly single strand of a conductor is used as fuse. These dropout fuses are connected between high voltage line and bushings with ACSR (Aluminum Conductor Steel Reinforced) conductors. Drop out fuse assemblies also contain lose connections. Fig. 5 shows thermograph of drop out fuses for 100kVA transformer installed at MUET, Jamshoro. It shows hot spot on one phase indicating a

FIG. 3. THERMOGRAPH SHOWING LOAD UNBALANCE ON 200KVA TRANSFORMER LOCATED AT QASIMABAD CITY, HYDERABAD

FIG. 4. THERMOGRAPH SHOWING LOSE CONNECTION ON HIGH VOLTAGE BUSHING OF 200KVA TRANSFORMER INSTALLED AT MUET, JAMSHORO

lose connection. Temperature of the hot spot is 93^0C whereas reference temperature is 51^0C. This identified lose connection can be forwarded to maintenance staff to avoid any unplanned outage. Line conductors/cables and service wires also contain lose connections, joints and unbalanced current flows, detectable through IR Thermography.

Fig. 6 shows thermograph indicating improper service line connections observed at residential society of MUET Jamshoro. Temperature of 53.5^0 is observed at hottest spot as compared to 29.5^0 for service lines. Identified service line connections are recommended for remedial actions using proper line taps. Fuses are installed with supply systems of various equipment in power system.

Fig. 7 shows thermograph of fuses installed at telephone exchange Hyderabad. Temperature of middle fuse is observed 95^0C whereas other fuses are at 64^0C. This variation in temperature indicates unbalanced loading on the system. Supply system for heavy industrial loads, panel boards, capacitor banks, circuit breakers and bus-bars are also checked through thermographic cameras. Thermographs show unbalanced loading, lose connections and improper joints. Identified problems are analyzed to set priority for maintenance work.

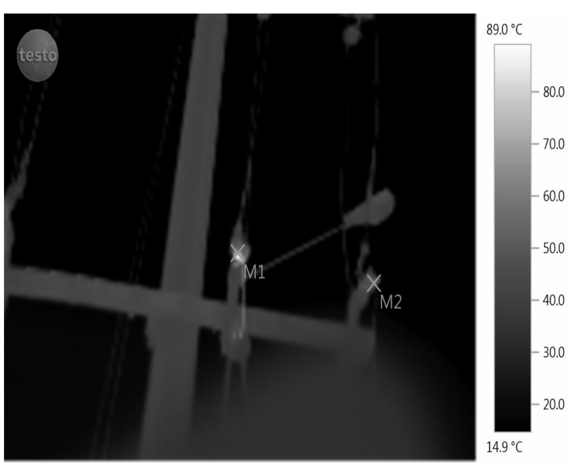


FIG. 5. THERMOGRAPH SHOWING LOSE CONNECTION AT DROP OUT FUSE ASSEMBLY OF 200KVA TRANSFORMER AT MUET, JAMSHORO

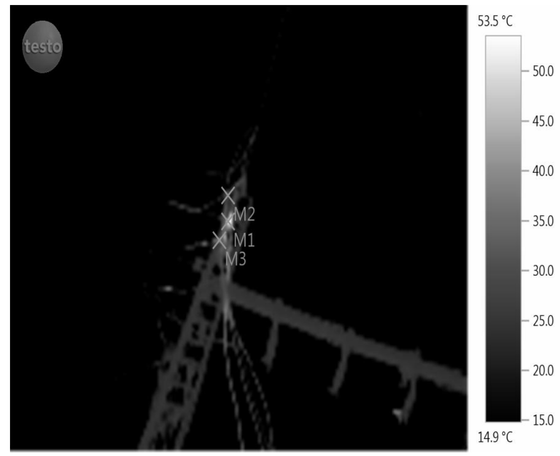


FIG. 6. THERMOGRAPH SHOWING LOSE CONNECTION AT SERVICE LINE CONNECTIONS AT MUET RESIDENTIAL SOCIETY, JAMSHORO

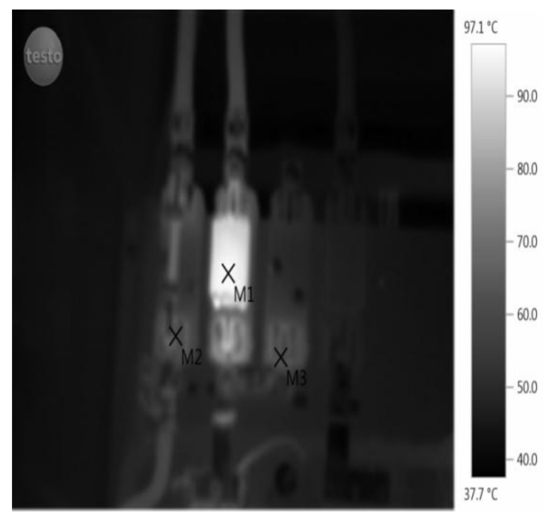


FIG. 7. THERMOGRAPH SHOWING UNBALANCED LOADING AT FUSES AT TELEPHONE EXCHANGE HYDERABAD

5. CONCLUSIONS

Old aged distribution system in HESCO is having problems of transformer damage, faults causing unplanned outages and high technical losses. Thermographic inspection is safe, reliable and fast inspection method to detect such problem at the earliest. Later preventive maintenance can be carried out to avoid unplanned disruptions. Improved efficiency, reliability and consumer satisfaction are the outcomes of thermographic inspection programs. Unbalanced and over loading of transformers is easily detectable by IR thermography from ground resulting in safety, accuracy, reliability and saving of time.

It is recommended that HESCO implement thermographic inspection procedures for performance improvement of distribution system. Initially one particular area may be selected for implementing the program and then based on the achieved benefits; this program may be extended to other areas and to other distribution utilities of Pakistan.

As an extension of this work, complete inspection program for different distribution system components and consumer wiring (including MUET, Jamshoro) is in progress including cost benefit analysis. In addition to that an automatic system will be analyzed in future to generate alarms based on temperature variations.

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